THE REGULATORY POLICY IMPLICATIONS OF THREE ALTERNATIVE ECONOMETRIC SUPPLY MODELS OF NATURAL GAS[1]

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1. Introduction

The shortage of natural gas in the United States has grown substantially in the last few years and is now at the level where it probably exceeds ten percent of total demands. Prior discovery of the lowest cost, highest volume reservoirs has been given as one reason for this state of affairs--the argument being that exploratory companies had found most of the high-productivity reservoirs by the early 1960's. But this is not a sufficient explanation, since rising resource costs alone would have resulted in relative price increases in natural gas and not in a large and systematic shortage. The additional condition is that the Federal Power Commission in the early 1960's set limits on field prices for new production approximate to the unregulated prices of the late 1950's, and then held these prices for most of the decade.[2] The combination of rising resource costs, general inflation, and frozen gas prices must have provided strong incentives for increased demands but no incentives for increased discoveries and production.

The shortage, and this rationale for the shortage, has resulted in widespread and concerted efforts to deregulate field prices. Increased prices resulting from deregulation, it is generally expected, would add to reserves and result in more production each year out of reserves; at the same time, demands for production would be dampened as users of boiler fuel replaced the more expensive gas with oil products or coal. But the question has been asked as to whether the tendency to clear markets of excess demand is sufficient reason for deregulation. If the increase in reserves resulted only

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[2] Stephen Breyer and Paul W. MacAvoy, "The Natural Gas Shortage and the Regulation of Natural Gas Producers," Harvard Law Review, Vol. 86, No. 6, April, 1973.

in payments of rents to owners of the source (land) resources, then many of the proponents of deregulation would likely be less enthusiastic.

Deregulation, if it were to take place, would not be accomplished in an afternoon. The 1973-1974 proposals of the Nixon Administration call for a series of substantial price increases, to be administered by one or the other agency, as regulation winds down over the rest of the decade.[3] The opposition in the Senate has proposed new procedures for the Federal Power Commission to use in allowing price increases; if these procedures were to be put into effect, the resulting prices would probably be only a few cents per Mcf greater than on new contracts signed this year. A few cents, rather than doubling of new contract prices, may be sufficient to clear the market of excess demand. The choice of the proper "interim" policy for the next few years depends on the effect of the price increase on the levels of additional production.

The size of the response of reserve accumulations and production to price changes is thus critical in policy determination for the next few years. Estimates of the response have been made by a number of sources, some on the basis of experience in the industry[4] and others on the basis of more formal modelling exercises.[5] An attempt should be made at this time to evaluate these estimates. This attempt is made below.

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[3]Paul W. MacAvoy and Robert S. Pindyck, "Alternative Regulatory Policies for Dealing with the Natural Gas Shortage," Bell Journal of Economics and Management Science, Vol. 4, No. 2, Autumn, 1973.

[4]National Petroleum Council, United States Energy Outlook, Washington, D.C., December, 1972.

[5]J. D. Khazzoom, "The FPC Staff's Econometric Model of Natural Gas Supply in the United States," Bell Journal of Economics and Management Science, Vol. 2, No. 1, Spring, 1971, and E. Erickson and R. Spann, "Supply Response in a Regulated Industry: The Case of Natural Gas," Bell Journal of Economics and Management Science, Vol. 2, No. 2, Spring, 1971

2. Background for This Work

For the past year and one-half a research group at MIT has been developing an econometric model of the natural gas industry, to be used in studying the effects of alternative regulatory policies on the wellhead price of gas.[6] That model is a set of within-module simultaneous equations. The supply module, a regional basis, has equations for drilling activity (in response to price and cost variables), and for new discoveries, extensions, and revisions for either oil-associated or non-associated gas (also in response to price variables, in response to drilling levels and to costs). This makes up reserve supply; under conditions of Federal Power Commission regulations (resulting in depressed prices and excess reserve demand), quantities of new reserves are determined by inserting the exogenous wellhead price of gas in the appropriate equations in any year. Production of gas out of reserves is determined in the model by assuming exogenous prices equal to marginal costs and by then relating marginal costs to actual reserve levels and to production levels. The model also contains a set of regional wholesale demand equations that relate demand to the size of final retail or wholesale markets, wholesale prices of gas, and prices of alternative fuels. Wholesale and field markets are linked together in the model by a set of pipeline price mark-up equations together with an input/output table that determines the distribution of gas from production regions to wholesale consumption regions.

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[6]This model was developed under National Science Foundation Grant #GI-34936. It is described in detail in P. W. MacAvoy and R.S. Pindyck "Alternative Regulatory Policies for Dealing with the Natural Gas Shortage," The Bell Journal of Economics and Management Science, Vol. 4, No. 2, Autumn, 1973.

The part of the model which is probably most open to controversy is the set of equations that explain reserve additions. Little is known about the exploration and discovery process--about the incentives for further exploration, the opportunities for significant finds (dependent on how much undiscovered gas remains under the ground in the United States) and the relation between _a priori_ opportunities and _a posteriori_ finds. The MIT research project approached the problem by specifying equations that offered an intuitive explanation for drilling activity, and then fitting these equations as best as one could the available data. Our approach began by assuming that drilling can be divided into two modes of behavior, depending on whether it is done _extensively_ or _intensively_.[7] The first reaches out into new areas, with the supposed result that the ratio of successful wells declines but the size of find per successful well increases; the second results in a higher success ratio but smaller finds. However as a result of data aggregation, it is impossible to determine _ex post_ whether drilling has been done in the extensive or intensive mode.[8] Regression equations fitted _ex post_ had a tendency to show increasing size of finds on higher gas prices for non-associated gas, but decreasing size on associated gas.

Other econometric models have been developed for natural gas exploration and discovery. Two in particular have received some attention and use very

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[7] In extensive drilling, few wells are drilled, but those that are drilled usually go out beyond the frontiers of recent discoveries to open up new geographical locations or previously neglected deeper strata at old locations. This might include drilling farther off-shore or on-shore but at very great depth. Here the probability of discovering gas is rather small, but the size of discovery may be comparatively large. When drilling is done intensively many wells are drilled in an area that has already proven itself to be a source for gas discovery. Here the probability of discovering gas is larger but the size of discovery is likely to be very small.

[8] See M. Subrahmanyam and K. Challa, "The Oil and Natural Gas Exploratory Process in the United States: A Framework for Analysis," unpublished research memorandum, October, 1973.

different formulations than that which was used in the MIT model. The first of these, developed by Khazzoom for the Federal Power Commission,[9] relates new discoveries, extensions and revisions to a distributed lag of past ceiling prices, oil prices, and prices of natural gas liquids. The model can be thought of as a set of reduced form equations (or equivalently a "black box") because it does not specify explicitly any structural relationships between prices, drilling activity, and discoveries. This is not to fault the model, since it is not at all clear what a correct specification for a structural form model of exploration and discovery would be, and the reduced form specification of Khazzoom's model is appropriate to a variety of "reasonable" structural forms. The second alternative supply model is that of Erickson and Spann,[10] a more structural model which contains logarithmic equations. The first equatic relates wildcatting activity to prices, previous success ratios, and other geographical and geological variables. The second relates the success ratio to prices and geological variables, and the last two relate average oil discovery size and gas discovery size respectively to prices and geological variables. Extensions and revisions are not covered by the model, but new discoveries are explained with more structural detail than is the case in the MacAvoy-Pindyck model.[11]

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[9] See J. Daniel Khazzoom, "The FPC Staff's Econometric Model of Natural Gas Supply in the United States," The Bell Journal of Economics and Management Science, Vol. 2, No. 1, Spring, 1971.

[10] E. W. Erickson and R. M. Spann, "Supply Response in a Regulated Industry: The Case of Natural Gas," The Bell Journal of Economics and Management Science, Vol. 2, No. 1, Spring, 1971.

[11] The MacAvoy-Pindyck model has an equation for total exploratory drilling, and then equations that relate average discovery size to attempted wells whether or not those wells are successful. Thus it lacks a description of the success ratio and could be thought of as a semi-reduced form or a variation on the Erickson and Spann model.

In this paper we re-estimate the Khazzoom and Erickson-Spann models using the same data as for the exploration and discovery part of the MacAvoy-Pindyck model.[12] Each of these models for exploration and discovery will then be simulated as a module of the MacAvoy-Pindyck overall model. We will thus produce three alternative sets of simulation results for natural gas reserves, production, and demand the first using the original exploration and discovery equations that were part of that model, the second using Khazzoom's equations for exploration and discovery, and the third the Erickson-Spann formulation for exploration and discovery. Each of the three models for exploration and discovery has a different degree of structural detail. By comparing the three sets of simulations, we will attempt to assess the appropriateness of the degree of detail--or the extent to which structural theory is helpful in explaining and predicting gas reserves.

In the next section we describe the Khazzoom and Erickson-Spann models for exploration and discovery, and then present the re-estimated form of those models. The fourth section of the paper presents the different simulation results used in the three alternative exploration and discovery formulations. Historical simulations will be performed first (in order to compare the fit of the three models), and then forecasts are made of natural gas production demand and supply through 1980 so that the long-run implications of these alternative formulations can be compared. Finally, the paper provides some speculation on the econometrics of natural gas exploration and discovery.

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[12]As we will see in the next section some minor re-specification of those models is necessary in order to make the variables consistent with the data used in the MacAvoy-Pindyck model.

3. Alternative Formulations of Natural Gas Exploration and Discovery

The "base case" for comparisons will be the exploration and discovery equations of the MacAvoy-Pindyck gas model. These equations were estimated using pooled data over 18 FPC production districts for the years 1964 through 1971. The exploration and discovery sub-model begins with an equation for total exploratory wells drilled for any district in any year as a function of previous revenues (REVD), previous average cost (ATCD), and average risk (RISKV) as measured by the variance of previous success rates. The equation, with regional dummy variables DDA, DDB, and DDC, is shown below with t-statistics in parentheses:

$$\begin{aligned} WXT = \underset{(9.17)}{439.39} &+ \underset{(3.81)}{934.53}DDA + \underset{(0.40)}{83.75}DDB + \underset{(3.24)}{137.48}DDC \\ &+ \underset{(2.22)}{3.156\times10^{-4}}REVD_{t-1} - \underset{(4.79)}{4.43\times10^{-3}}ATCD_{t-1} \\ &- \underset{(-2.74)}{2.13\times10^{-7}}RISKV \end{aligned} \qquad (1)$$

$R^2 = 0.495$ $\qquad$ $F = 17.2$ $\qquad$ S.E. = 193.6 $\qquad$ DW = 0.36

Equations are estimated for average discovery size of pools and fields of non-associated gas (SIZEDN) and for average discovery size of associated gas (SIZEDA). These variables thought to affect size are the past prices of gas and oil, past drilling costs, and the cumulative number of wells drilled (CWXT). The relationship of discovery size ot cumulative wells drilled is hypothesized to be negative because of depletion effects that occur over time in a reservoir region in which mnay wells are drilled. The estimated equations are shown on the following page.

$$SIZEDN = \underset{(-2.78)}{815.62} - \underset{(-0.94)}{600.69}DDA + \underset{(0.63)}{189.70}DDB + \underset{(6.52)}{825.43}DDC + \underset{(2.05)}{28.89}(PG_{t-1} + PG_{t-2} + PG_{t-3})/$$

$$+ \underset{(5.86)}{0.0131}(ATCD_{t-1} + ATCD_{t-2} + ATCD_{t-3})/3 - \underset{(-3.18)}{0.301}CWXT_{t-1}$$

$R^2 = 0.631$ $\quad$ $F = 29.9$ $\quad$ $S.E. = 578.3$ $\quad$ $DW = 0.74$ $\quad$ (2)

$$SIZEDA = \underset{(1.64)}{50.60} + \underset{(2.65)}{106.96}DDA + \underset{(2.67)}{48.34}DDB + \underset{(4.02)}{30.02}DDC - \underset{(-1.64)}{14.30}(PO_{t-1} + PO_{t-2} + PO_{t-3})/3$$

$$+ \underset{(2.24)}{3.138\text{x}10^{-4}}(ATCD_{t-1} + ATCD_{t-2} + ATCD_{t-3})/3 - \underset{(-1.84)}{4.590\text{x}10^{-3}}CTXT_{t-1}$$

$R^2 = 0.601$ $\quad$ $F = 26.3$ $\quad$ $S.E. = 34.6$ $\quad$ $DW = 1.06$ $\quad$ (3)

New discoveries of associated gas and non-associated gas (NDA,NDNA) are thus given by:

$$NDNA = SIZEDN \cdot WXT \qquad (4)$$

$$NDA = SIZEDA \cdot WXT \qquad (5)$$

Separate equations are estimated for non-associated and associated extensions and revisions. Non-associated and associated extensions depend on exploratory drilling activity as well as previous non-associated and associated new discoveries:

$$XN = \underset{(0.430)}{2.20\text{x}10^4} + \underset{(5.63)}{1.33\text{x}10^6}DDA + \underset{(11.04)}{1.56\text{x}10^6}DDB + \underset{(0.55)}{3.639\text{x}10^5}DDC + \underset{(1.93)}{237.1}WXT_{t-1} + \underset{(1.24)}{0.137}NDNA$$

$R^2 = 0.725$ $\quad$ $F = 67.6$ $\quad$ $S.E. = 3.2\text{x}10^5$ $\quad$ $DW = 0.87$ $\quad$ (6)

$$XA = \underset{(-0.11)}{-1054.93} + \underset{(5.20)}{2.323\text{x}10^5}DDA + \underset{(4.44)}{1.205\text{x}10^5}DDB - \underset{(0.17)}{1947.44}DDC + \underset{(2.11)}{48.00}\ WXT_{t-1} + \underset{(2.53)}{0.722}NDNA$$

$R^2 = 0.693$ $\quad$ $F = 57.7$ $\quad$ $S.E. = 5.8\text{x}10^4$ $\quad$ $DW = 1.60$ $\quad$ (7)

Associated and non-associated revisions, on the other hand, depend largely on the previous year's change in reserves (ΔR):

$$RN = \underset{(1.19)}{6.87 \times 10^4} + \underset{(5.95)}{1.138 \times 10^6 DDA} - \underset{(-3.60)}{6.864 \times 10^6 DDB} + \underset{(0.373)}{3.438 \times 10^4 DDC} + \underset{(4.963)}{0.239 \Delta R_{t-1}}$$

$$R^2 = 0.398 \qquad F = 18.2 \qquad S.E. = 4.5 \times 10^5 \qquad DW = 1.65 \qquad (8)$$

$$RA = \underset{(-0.07)}{-2234.90} + \underset{(4.56)}{4.863 \times 10^5 DDA} + \underset{(3.04)}{3.240 \times 10^5 DDB} + \underset{(0.69)}{3.550 \times 10^4 DDC} + \underset{(3.94)}{0.106 \Delta R_{t-1}}$$

$$R^2 = 0.289 \qquad F = 11.2 \qquad S.E. = 2.5 \times 10^5 \qquad DW = 1.71 \qquad (9)$$

Note that district dummy variables are used in all of these equations, and the same district dummies will be used in the Khazzoom and Erikson-Spann models. Finally, additions/ to reserves are given by total new discoveries plus extensions and revisions:

$$DR = NDNA + NDA + XN + XA + RN + RA \qquad (10)$$

This reserve accounting identity excludes, of course, losses and changes in underground storage.

The Khazzoom model relates aggregated new discoveries (ND = NDNA + NDA) to the price of gas (PG), the price of oil (PO) and the price of natural gas liquids, (PL). (Since we had no data available for natural gas liquids, this variable had to be omitted from our version of the Khazzoom model.) The district dummy variables used by Khazzoom were the same as those used in the MacAvoy-Pindyck model, and these include DDA for Louisana South, DB for the Permian producing region, DDC for Kansas, Oklahoma, and Texas Railroad Commission districts 1, 2, 3, 4 and 10. We estimated Khazzoom's discovery equation over the same 18 production districts and/ the years 1965-1969 as in the

M/P model. The resulting equation is given below:

$$
\begin{aligned}
ND = \underset{(-0.38)}{-42463} + \underset{(1.41)}{1.647\times10^{5}}DDA + \underset{(1.14)}{7.862\times10^{4}}DDB + \underset{(0.92)}{3.401\times10^{4}}DDC \\
+ \underset{(0.23)}{1086.3}(PG_{-1} + PG_{-2})/2 + \underset{(0.25)}{10844}(PO_{-1} + PO_{-2})/2 + \underset{(11.99)}{0.685}ND_{-1}
\end{aligned}
$$

$R^2 = .895$ S.E. $= 1.23\times10^5$ F $= 100.5$ DW $= 2.05$ (11)

Our version of Khazzoom's extensions and revisions equation is shown below, again using the price of gas, the price of oil, previous new discoveries and lagged extensions plus revisions.

$$
\begin{aligned}
XR = \underset{(-.03)}{-16252} + \underset{(2.283)}{2.209\times10^{6}}DDA + \underset{(2.55)}{1.201\times10^{6}}DDB - \underset{(1.06)}{1.653\times10^{5}}DDC - \underset{(-0.04)}{946.0}\ PG + \underset{(0.17)}{3.209\times10^{4}}PO \\
+ \underset{(2.77)}{0.645}ND_{t-1} + \underset{(2.72)}{0.325}XR_{t-1}
\end{aligned}
$$

$R^2 = .814$ S.E. $= 6.11\times10^5$ F $= 56.2$ DW $= 1.48$ (12)

Note that the price variables (PG and PO) are statistically insignificant in both equations. This is a change in results--Khazzoom's own estimates showed a significant fit for the price of gas (which in both of his equations had a t-statistic greater than 2). Since it was not possible to use the original equations in our simulation foremat, the alternatives were (1) use equations 11 and 12 (2) change the basic form of Khazzoom's equations to produce higher t-statistics for price. The first seemed preferable, in order to preserve the essential nature of Khazzoom's approach.

The reader might wonder why our estimated version of Khazzoom's equations differ considerably from Khazzoom's original estimates; in particular why the price terms have become insignificant. We have, of course, estimated Khazzoom's equations over a somewhat shorter time period than he did originally (1964-1969 versus 1961-1969), and one might suspect that by truncating the estimation period

we have eliminated just those years (1961-1963) over which prices and discoveries had their greatest variance. If this was the case, than it would account for the loss of significance in the price terms in our estimates of Khazzoom's equations.

In Table A we show, for eight representative production districts around the country, new contract prices for the years 1952 to 1969, and new discoveries and extensions and revisions for 1956 to 1969 (data on these latter variables was not available before 1956). Note that between 1960 and 1969 discoveries dropped almost consistently in Louisana South, Mississippi, Kansas, Texas 6, and Texas 10. New contract prices also dropped in those districts between 1960 and 1963, then rose between 1963 and 1969, so that the elimination of the 1961 to 1963 period (at least for those districts) would indeed reduce the positive correlation between price and discoveries. In Texas 3 and Texas 4 discoveries increased from 1960 to 1967 and then decreased from 1967 to 1969, while prices showed some decrease between 1960 and 1963 and then increased thereafter. Thus eliminating the 1961 to 1963 years from the estimation period should for these two districts improve the positive correlation between price and discoveries. Of course our regressions are also picking up cross-sectional variance between price and discoveries, but this does not change much from year to year. Putting this together, it would be reasonable to expect that decreasing prices in the majority of districts between 1960 and 1963 contributed to the significance of the Khazzoom's price terms when his equations were estimated over the longer time period.

There is another problem with Khazzoom's formulation however, and that is that both of his equations contain a lagged dependent variable. In the new discoveries equation this variable accounts for most of the explained variance,

so that in fact the equation represents little more than a simple first order autoregressive model for a random process. If the errors are serially correlated (and there is no reason to believe that they are not) than his estimates of the price coefficients are inconsistent in any case.

The model constructed by Erickson and Spann seeks first to explain total wildcatting activity. In order to make their structural format consistent with our data base, some reformulation was necessary. For example, we reformulated the drilling equation to include all exploratory wells drilled instead of just new pool and new field wildcats. The average depth of drilling variable thus also applies to all exploratory wells and not just wildcats. Erickson and Spann use two variables relating to past drilling activity, the first of these is wildcats drilled by major companies in a given district in a given year as a percent of total U. S. wildcats drilled by all companies in that year, and the second is wildcats drilled by major companies in a given district in a given year as a percent of total U. S. wildcats drilled by those companies in that year. We did not have access to this data and therefore used a single variable (WRATIO), which is the relative fraction of total exploratory wells drilled in a particular district in a particular year as a fraction of total exploratory wells drilled in the entire United States. Finally, the variables used by Erickson and Spann for Texas shutdown days were omitted from our version of their model since data for them was unavailable.

Our version of the Erickson and Spann wildcatting equation is shown below, using the same logarithmic form as Erickson and Spann do, but relating total exploratory wells drilled to deflated gas prices (PGD) and deflated oil prices (POD), previous success ratios (SR), average footage (AFX), and the activity variable (WRATIO) mentioned above:

$$\begin{aligned}\log WXT = {} & \underset{(45.83)}{9.018} + \underset{(0.01)}{1.577\text{x}10^{-4}}DDA \\ & \underset{(-0.09)}{-.0029}DDB - \underset{(-1.13)}{.0172}DDC - \underset{(-0.98)}{0.033} \log PGD \\ & + \underset{(1.02)}{0.065} \log POD - \underset{(-0.44)}{0.0067} \log SR_{t-1} \\ & \underset{(00.36)}{-0.0061} \log AFX_{t-1} + \underset{(121.63)}{1.006} \log WRATIO\end{aligned} \tag{14}$$

R^2 = .995 S.E. = 0.063 F = 2497 DW = 1.98

Next, our version of the Erickson and Spann success ratio equation relates that variable to the deflated price of gas and the deflated price of oil, again in logarithmic form:

$$\begin{aligned}\log SR = {} & \underset{(-7.91)}{-4.869} - \underset{(-0.70)}{0.148}DDA + \underset{(2.67)}{0.554}DDB + \underset{(1.22)}{0.121}DDC \\ & + \underset{(2.51)}{0.570} \log PGD + \underset{(3.68)}{1.419} \log POD\end{aligned} \tag{15}$$

R^2 = .274 S.E. = 0.443 F = 6.93 DW = 0.72

Finally, an average gas discovery size equation (for both non-associated and associated gas) is given, relating that variable to deflated oil and gas prices, and the previous period's success ratio:

$$\log SIZE = \underset{(0.28)}{0.804} + \underset{(3.61)}{2.693DDA} + \underset{(1.92)}{1.464DDB} \tag{16}$$
$$+ \underset{(4.43)}{1.564DDC} + \underset{(2.20)}{1.826 \log PGD} + \underset{(0.24)}{0.348 \log POD}$$
$$\underset{(-0.81)}{-0.309 \log SR_{t-1}}$$
$$R^2 = .268 \quad S.E. = 1.568 \quad F = 5.57 \quad DW = 0.65$$

While the fit of this model leaves something to be desired, particularly for the success ratio and size equations, what is most startling is that the results, including the signs of several of the coefficients, differ considerably from Erickson and Spann's original results. For example, one sees reversals in the signs of the coefficients of the price of gas and average footage in the wells equation, and in the price of gas and the price of oil in the success ratio equation. Most important, the price elasticities that result from our estimates of these equations are very different from those implied by the original estimates. The own price elasticity of gas discoveries, for example, is 2.36 (the sum of the elasticities of -.033 for wildcat drilling, .570 for the success ratio, and 1.826 for the average size), as compared with 0.69 for Erickson and Spann's original estimates. Certainly simulations of this model are likely to show a much greater response to price stimulation than was the case when the original estimates were used, but what is disturbing is that these elasticities changed so dramatically when the model was estimated over a different time period.

Erickson and Spann estimated their original equations over the period 1946 to 1959, while we have re-estimated them over the period 1964 to 1969. As can be seen from Table A, new contract prices in all districts showed

much greater percentage increases from 1952 to 1958 than they did from 1960 to 1969. New discoveries, on the other hand, did not show such a dramatic percentage increase over the earlier period. Thus it is very reasonable to expect that Erickson and Spann's model would show much smaller price elasticities when estimated over the earlier period. While that explains why the elasticities are greater when the model is estimated over the later time period, their model nonetheless seems to be considerably over-estimating the price elasticity. The problem may be in their average size equation, which indicates (according to the estimated price elasticity of 1.826) that small price increases tend to result in very large increases in discovery size. The equation has a low R^2 and an F-statistic of only 5.6, so that most of the variance in average size is unexplained and the significance of the equation as a whole is questionable. Since Erickson and Spann's three equations are logarithmic, the price elasticities add across equations, so that a spurious elasticity in the size equation becomes reflected in the overall price elasticity for discoveries.

TABLE A (Source: Foster Associates)

New Contract Prices

	1952	1956	1958	1960	1963	1967	1969
La. South	15.3	18.9	21.8	22.1	19.4	19.9	21.1
Mississippi	NA	19.4	22.1	19.1	16.6	18.2	20.5
Kansas	9.8	12.9	12.9	14.8	14.0	15.4	15.6
Permian	9.0	10.1	15.2	15.1	15.3	16.9	16.7
Texas 3	13.6	15.6	18.8	16.9	13.1	16.0	17.0
Texas 4	7.0	13.5	15.8	17.2	16.0	16.1	18.3
Texas 6	7.8	11.8	11.4	12.4	13.0	14.0	16.0
Texas 10	8.6	14.6	18.6	16.8	16.8	16.9	20.0

Discoveries

	1956	1958	1960	1963	1967	1969
La. South	1.495E+06	1.803E+06	2.187E+06	1.733E+06	1.699E+06	1.182E+06
Mississippi	4.34E+04	7.42E+04	2.092E+05	5.03E+04	5.57E+03	9.22E+04
Kansas	1.943E+05	2.69E+04	1.556E+05	8.54E+04	4.468E+04	1.29E+04
Permian	5.309E+05	7.384E+05	3.786E+05	3.937E+05	3.971E+05	3.512E+05
Texas 3	4.054E+05	3.794E+05	4.191E+05	4.636E+05	6.626E+05	3.775E+05
Texas 4	9.557E+05	8.704E+05	6.731E+05	9.896E+05	1.218E+06	5.289E+05
Texas 6	1.399E+05	1.033E+05	2.959E+05	9.79E+04	2.30E+04	2.88E+04
Texas 10	9.43E+04	1.993E+05	7.31E+04	5.55E+04	1.113E+05	3.71E+04

Extensions and Revisions

	1956	1958	1960	1963	1967	1969
Lousiana South	2.853E+06	3.419E+06	4.042E+06	5.492E+06	6.482E+06	2.983E+06
Mississippi	-2.95E+04	4.059E+05	3.16E+04	-1.050E+05	9.01E+04	5.10E+04
Kansas	1.644E+06	1.489E+05	1.281E+05	1.249E+05	2.077E+05	4.878E+05
Permian	2.431E+06	-1.485E+06	6.346E+05	1.209E+06	3.924E+06	-6.89E+04
Texas 3	9.286E+05	4.397E+05	3.744E+05	6.208E+05	2.762E+05	-5.629E+05
Texas 4	2.959E+06	3.255E+05	6.556E+05	4.183E+05	6.759E+05	-1.078E+05
Texas 6	2.643E+05	3.818E+05	6.116E+05	1.694E+05	1.085E+05	6.62E+04
Texas 10	3.438E+05	6.945E+05	-5.361E+05	4.98E+04	1.216E+06	3.92E+04

4. Simulations of the Three Models

The three formulations for exploration and discovery estimated above can now be simulated as part of the complete supply-demand gas model in order to determine their alternative impacts on production, supply, demand, and excess demand. We begin by performing an historical simulation - a "backcast"- of each model over the period 1965 through 1971. Some explanation is needed for how these simulations are performed.

The Khazzoom model predicts both new discoveries and extensions and revisions, so that the two equations of that model can simply be substituted for the seven equations of the MacAvoy-Pindyck model that predict wells, discoveries, extensions, and revivsions. The Erickson-Spann model, however, predicts only new discoveries, so that a method was needed to generate extensions and revisions. We chose to substitute the three Erickson-Spann exploration and discovery equations in place of the equations of the MacAvoy-Pindyck that also predict new discoveries, but to retain the four extensions and revisions equations of that model. In performing the historical simulation we used the actual values for associated and non-associated new discoveries as inputs to the extensions and revisions equations rather than the predicted values generated by the Erickson-Spann discovery equations. In a sense this gives some "benefit of doubt" to the Erickson-Spann formulation, since it prevents accumulated errors in new discoveries from affecting extensions and revisions.

It is important to point out that simulated demand for production will be slightly different for each model formulation, even though the only difference between the models are in the exploration and discovery equations. The reason for this is that demand for production depends on the wholesale

price (either for sales for resales or for mainline sales). The wholesale price in turn is based on a pipeline mark-up over an average "rolled in" wellhead price. The average "rolled in" price is computed separately for each production region, and depends on the current period's production level in that region (since in computing rolled-in prices, new contract prices are weighted proportionately to new production).* Production out of reserves, on the other hand, is itself a function of the average rolled-in price and year-end reserves, which means that the rolled-in price and production out of reserves are determined simultaneously, each one depending on the other and on year-end reserves. Thus new reserves and new production, which differ between models, will lead to different prices at the field and wholesale level--and ultimately to different demands at wholesale.

The results of these simulations are shown in table 2, together with the root-mean-square (RMS) and mean simulation errors for each variable. Note that over this seven year time range the MacAvoy-Pindyck formulation performs best in terms of new discoveries, with an RMS simulation error of 1.19×10^6 versus 1.49×10^6 for the Khazzoom formulation and 1.70×10^6 for the Erickson-Spann formulation. The Khazzoom formulation has the lowest RMS error for additions to reserves, since the aggregated extensions plus revisions equations of that model "tracks" the historical data more closely than do the disaggregated MacAvoy-Pindyck equations. It is questionable how meaningful this is, however, since (a) the Khazzoom extensions and revisions equation depends on new discoveries, which are being underpredicted--so that if Khazzoom's new discoveries tracked better his extensions and revisions

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*For a more detailed description of how rolled-in prices are computed, see footnote 11, page 462, of MacAvoy and Pindyck, op.cit.

TABLE 1 : HISTORICAL SIMULATIONS

New Discoveries (ND)

	Khazzoom	E-S	M-P	Actual
1965	4.927510E+06	3.538782E+06	5.535778E+06	6.300903E+06
1966	4.404835E+06	3.281833E+06	5.223635E+06	5.852670E+06
1967	3.702763E+06	3.139686E+06	4.832344E+06	4.993816E+06
1968	3.269285E+06	2.806881E+06	4.961565E+06	2.619571E+06
1969	2.865252E+06	2.813043E+06	5.120569E+06	3.384377E+06
1970	2.567956E+06	3.242253E+06	5.091229E+06	4.705534E+06
1971	2.327184E+06	4.496687E+06	5.036997E+06	4.487873E+06
Mean Error	-1.182851E+06	-1.289368E+06	493910	
RMS Error	1.491819E+06	1.697857E+06	1.192642E+06	

Additions to Reserves (DR)

	Khazzoom	E-S	M-P	Actual
1965	1.629169E+07	1.527245E+07	1.726944E+07	2.060386E+07
1966	1.446441E+07	1.234475E+07	1.472465E+07	1.845507E+07
1967	1.296658E+07	1.096654E+07	1.334064E+07	2.037024E+07
1968	1.179325E+07	9.998183E+06	1.282172E+07	1.156165E+07
1969	1.086904E+07	9.334178E+06	1.276122E+07	7.687277E+06
1970	1.008629E+07	9.626320E+06	1.264768E+07	1.017752E+07
1971	9.501674E+06	1.106876E+07	1.232871E+07	9.127735E+06
Mean Error	-1.7[illegible]5773E+06	-2.767446E+06	-298470	
RMS Error	3.773208E+06	4.831703E+06	4.108010E+06	

Total Reserves (R)

	Khazzoom	E-S	M-P	Actual
1965	2.701793E+08	2.670136E+08	2.689833E+08	2.744760E+08
1966	2.685852E+08	2.612699E+08	2.655214E+08	2.761155E+08
1967	2.653688E+08	2.541120E+08	2.605574E+08	2.788209E+08
1968	2.609601E+08	2.460409E+08	2.549760E+08	2.717619E+08
1969	2.556177E+08	2.373431E+08	2.491455E+08	2.595080E+08
1970	2.492693E+08	2.286638E+08	2.427182E+08	2.487186E+08
1971	2.416458E+08	2.203687E+08	2.350068E+08	2.366724E+08
Mean Error	-4.920978E+06	-1.875160E+07	-9.880681E+06	
RMS Error	7.680908E+06	1.966672E+07	1.136339E+07	

Supply of Production (QS)

	Khazzoom	E-S	M-P	Actual
1965	1.849915E+07	1.837341E+07	1.840427E+07	1.609538E+07
1966	1.881624E+07	1.851822E+07	1.861616E+07	1.729718E+07
1967	1.908216E+07	1.863734E+07	1.881758E+07	1.825886E+07
1968	1.924944E+07	1.867346E+07	1.900726E+07	1.926184E+07
1969	1.939262E+07	1.871194E+07	1.927659E+07	2.065781E+07
1970	1.977939E+07	1.908403E+07	1.985418E+07	2.192786E+07
1971	2.063416E+07	2.023416E+07	2.091754E+07	2.213746E+07
Mean Error	-26174.3	-486261	-106115	
RMS Error	1.569353E+06	1.799446E+06	1.470543E+06	

Demand for Production (QD)

	Khazzoom	E-S	M-P	Actual
1965	1.461852E+07	1.461891E+07	1.474638E+07	1.464327E+07
1966	1.565754E+07	1.565877E+07	1.601850E+07	1.600178E+07
1967	1.668511E+07	1.668765E+07	1.741242E+07	1.700058E+07
1968	1.780414E+07	1.780864E+07	1.875062E+07	1.838875E+07
1969	1.896488E+07	1.897195E+07	2.001379E+07	1.987565E+07
1970	2.016419E+07	2.017323E+07	2.131770E+07	2.139037E+07
1971	2.156278E+07	2.156043E+07	2.264557E+07	NA
Mean Error	-567670	-563541	159836	
RMS Error	694431	689298	236587	

Average Field Price (rolled in) (PG)

	Khazzoom	E-S	M-P	Actual
1965	16.9006	16.8935	16.8535	16.8539
1966	16.9759	16.9621	16.9283	17.0824
1967	17.0975	17.0762	17.0497	17.1384
1968	17.2418	17.2164	17.213	17.3982
1969	17.4895	17.4607	17.4999	17.6621
1970	18.2005	18.166	18.2579	18.0984
1971	19.6714	19.7765	19.8084	19.2641
Mean Error	0.01137	0.00771	0.016166	
RMS Error	0.187355	0.22698	0.243185	

Average Wholesale Price (PW)

	Khazzoom	E-S	M-P	Actual
1965	27.8193	27.8161	27.6834	26.4328
1966	28.103	28.096	27.7579	26.295
1967	28.3944	28.3821	27.6901	25.925
1968	28.7375	28.7199	27.7784	25.7893
1969	29.1293	29.1068	28.0162	26.5886
1970	29.9017	29.8769	28.6643	27.785
1971	31.2467	31.3139	29.9764	NA
Mean Error	2.21159	2.19702	1.46243	
RMS Error	2.26998	2.25464	1.50485	

would track more poorly; and (b) the autoregressive component of Khazzoom's equation is helping it pick up trend, but what is allowing the model to pick up trend may prevent it from picking up turning points. What we are really after is a tool for analyzing the impacts of alternative regulatory price policies and the autoregressive nature of Khazzoom's model is likely to prevent it from being useful for this purpose.

The Erickson-Spann formulation has the largest RMS error for additions to reserves; but this is entirely a result of its underpredicting new discoveries, (since it is being simulated using the extenions and revisions equation of the M-P model, with actual values of new discoveries as inputs to those equations). The Erickson-Spann model also has the largest underprediction of the supply of production out of reserves, again because it underpredicts new discoveries, Finally, the simulated values for the demand for production out of reserves is roughly the same in all three formulations; again the differences are attributable to the different predicted rolled-in prices that result from different supply predictions, but these differences are not substantial on this side of the model.

It is also informative to simulate the three formulations over a future time horizon in order to compare their long run dynamic behavior. We performed forecast simulations over the time period 1971 through 1980, using three alternative sets of assumptions about regulatory policy for each model simulated. The first policy is called "cost of service" regulation. Since it requires historical average cost pricing of the FPC probably it; implies wellhead price increases of 1¢ per mcf per annum on new contracts. The second policy, which we call a "status quo" policy, assumes that FPC regulatory policy of 1970 through 1972 is continued by allowing wellhead price increases on new con-

tracts of about 3¢ per mcf per annum. Finally, a "deregulation" policy is simulated in which new contract prices are allowed to rise by 15¢ in 1974 and then an additional 3¢ per annum after 1974. (For a detailed description of these three alternative policies, see MacAvoy and Pindyck, op.cit.). In all of the forecasts, exogenous variables (such as the price of oil, per capita GNP) were assumed to follow the "medium" growth paths as described in that article.

Tables 2A, 2B, and 2C show the forecasts results using the Khazzoom exploration and discovery equations. Those results reflect the lack of price sensitivity in the Khazzoom equations, as there is almost no response in reserve additions to increases in the wellhead price (compare the "deregulation" case with the "cost of service" case). Thus, even under the "deregulation" policy, excess demand grows steadily and reaches a level of more than seven trillion cubic feet by 1980.

Forecasts results using the Erickson-Spann exploration and discovery equations are shown in Tables 3A, 3B and 3C. What we find is that the model is extremely sensitive to price, so that under "deregulation" new discoveries increase about ten fold between 1971 and 1980, production out of reserves more than doubles in that time period, and we have excess supplies of about 18 trillion cubic feet by 1980.

Again, this is because of very large supply elasticities for new discoveries with respect to oil and gas prices in the Erickson-Spann formulation. Since the equations are logarithmic, we can add the supply elasticities of well drilled, success ratios and size. If we do this we find that the

elasticity of total discoveries with respect to the deflated gas price is equal to about 2.36, and the elasticity of total discoveries with respect to the deflated oil price is equal to about 1.83. These elasticities apply only to new discoveries and not total additions to reserve; the elasticities for additions to reserves are about twice as large since new discoveries contribute to extensions and revisions. Thus a doubling of the wellhead price (under the "regulation" policy) can result in a ten-fold increase in discoveries.

The M-P model shows (in Tables 4A, B, and C) excess demands of about ten trillion cubic feet in 1980 under "cost of service" regulation, excess demand of about 6 trillion feet in 1980 under "status quo" regulation, and the elimination of excess demand by 1979 under the "deregulation" policy. Remember that what we are calling "deregulation" is not really deregulation--we are not permitting complete decontrol of the wellhead price, but simply allowing price to increase by a specified amount. We picked a price increase of 15¢ per mcf in 1974 (with further price increases of 3¢ per annum) because that came close to doubling the wholesale price by the end of the decade, (and as such would be "in line" with policies of the Cost of Living Council). Now the question, of course, is whether that price increase is too small (as suggested by the Khazzoom formulation) or is too large (as suggested by the Erickson-Spann formulation). In order to have market clearing by 1980 with the Khazzoom formulation, it would be necessary to have a price increase in 1974 of something closer to 50¢ per mcf. In order to have markets just clear by 1980 (with little or no excess supply) with the Erickson-Spann formulation, an additional price increase in 1974 of 2 or 3¢ (beyond the 3¢ per annum price increase) would probably be sufficient.

TABLE 2A: FORECAST WITH KHAZZOOM EQUATIONS AND COST OF SERVICE REGULATION

	ND	DR	R	QS
1971	3.237669E+06	7.877531E+06	2.375430E+08	2.213746E+07
1972	3.209478E+06	9.926770E+06	2.315951E+08	1.926155E+07
1973	2.772086E+06	1.055713E+07	2.228493E+08	2.283661E+07
1974	2.752026E+06	1.101981E+07	2.143709E+08	2.320957E+07
1975	2.750732E+06	1.136411E+07	2.062028E+08	2.343814E+07
1976	2.845694E+06	1.157264E+07	1.983053E+08	2.359138E+07
1977	2.909427E+06	1.173081E+07	1.906873E+08	2.370998E+07
1978	2.961369E+06	1.186503E+07	1.833419E+08	2.382155E+07
1979	2.998264E+06	1.196299E+07	1.762523E+08	2.394350E+07
1980	3.025669E+06	1.203702E+07	1.693986E+08	2.408792E+07

	QD	ED	WP	TC
1971	2.286837E+07	730912.	29.4413	19.2641
1972	2.439862E+07	5.137072E+06	30.5912	20.4404
1973	2.599638E+07	3.159776E+06	34.4503	24.8665
1974	2.795749E+07	4.747920E+06	36.4006	26.5189
1975	3.014173E+07	6.703584E+06	38.2292	27.9888
1976	3.236976E+07	8.773384E+06	39.9264	29.3397
1977	3.464538E+07	1.093539E+07	41.5287	30.6089
1978	3.699746E+07	1.317590E+07	43.0597	31.8208
1979	3.945285E+07	1.550934E+07	44.5353	32.9911
1980	4.203714E+07	1.794922E+07	45.9673	34.1302

TABLE 2b: FORECAST WITH KHAZZOOM EQUATIONS AND 'STATUS-QUO' REGULATION

	ND	DR	R	QS
1971	3.237669E+06	7.877531E+06	2.375430E+08	2.213740E+07
1972	3.209478E+06	9.926770E+06	2.315951E+08	1.926155E+07
1973	2.772086E+06	1.055713E+07	2.228493E+08	2.283661E+07
1974	2.752026E+06	1.099788E+07	2.141446E+08	2.341630E+07
1975	2.763320E+06	1.132719E+07	2.054648E+08	2.391323E+07
1976	2.886917E+06	1.154449E+07	1.967807E+08	2.434570E+07
1977	2.987451E+06	1.123975E+07	1.831354E+08	2.473450E+07
1978	3.082903E+06	1.191693E+07	1.795601E+08	2.509659E+07
1979	3.166895E+06	1.207658E+07	1.710755E+08	2.544568E+07
1980	3.243517E+06	1.222087E+07	1.626937E+08	2.579269E+07

	OD	ED	WP	PG
1971	2.287107E+07	733616.	29.4217	19.2641
1972	2.440630E+07	5.144752E+06	30.5632	20.4404
1973	2.601082E+07	3.174208E+06	34.4232	24.8665
1974	2.794022E+07	4.523920E+06	36.7361	26.956
1975	3.002616E+07	6.112928E+06	39.1651	29.1389
1976	3.206994E+07	7.724240E+06	41.6445	31.405
1977	3.406269E+07	9.328192E+06	44.1749	33.7481
1978	3.602502E+07	1.092843E+07	46.7549	26.1635
1979	3.797867E+07	1.253299E+07	49.3812	38 6454
1980	3.994640E+07	1.415371E+07	52.0501	41.1984

TABLE 2C: FORECAST WITH KHAZZOM EQUATIONS AND 'DEREGULATION' POLICY

	M	DR	R	QS
1971	3.237669E+06	7.877531E+06	2.375430E+08	2.213746E+07
1972	3.209478E+06	9.926770E+06	2.315951E+08	1.926155E+07
1973	2.772086E+06	1.055713E+07	2.223493E+08	2.283661E+07
1974	2.752026E+06	1.086632E+07	2.123010E+08	2.510090E+07
1975	2.838863E+06	1.122224E+07	2.015484E+08	2.585747E+07
1976	3.067408E+06	1.157170E+07	1.908692E+08	2.635130E+07
1977	3.236516E+06	1.190701E+07	1.803890E+08	2.671997E+07
1978	3.397512E+06	1.221265E+07	1.701616E+08	2.703019E+07
1979	3.532955E+06	1.248243E+07	1.602011E+08	2.731419E+07
1980	3.654589E+06	1.272038E+07	1.505073E+08	2.759270E+07

	QD	FD	WP	PG
1971	2.287558E+07	738128.	29.3314	19.2641
1972	2.441965E+07	5.158096E+06	30.4861	20.4404
1973	2.603718E+07	3.200576E+06	34.3123	24.8665
1974	2.765851E+07	2.557616E+06	39.5063	30.5757
1975	2.925366E+07	3.396192E+06	43.478	34.5267
1976	3.067259E+07	4.321296E+06	47.2578	38.2448
1977	3.193800E+07	5.218032E+06	50.9679	41.8876
1978	3.308966E+07	6.059472E+06	54.6597	45.5132
1979	3.416286E+07	6.948672E+06	58.355	49.1623
1980	3.519066E+07	7.597952E+06	62.064	52.8323

TABLE 3A: FORECAST WITH ERICKSON-SPANN EQUATIONS 'COST OF SERVICE' REGULATION

	ND	DR	R	QS
1971	4.488216E+06	9.128078E+06	2.365796E+08	2.213746E+07
1972	6.057225E+06	1.014869E+07	2.282570E+08	1.943992E+07
1973	1.212802E+07	1.885488E+07	2.241638E+08	2.403787E+07
1974	1.511010E+07	2.492837E+07	2.245598E+08	2.575056E+07
1975	1.587223E+07	2.787106E+07	2.265622E+08	2.723230E+07
1976	1.507953E+07	2.779891E+07	2.275690E+08	2.831958E+07
1977	1.483610E+07	2.705269E+07	2.272367E+08	2.909067E+07
1978	1.457460E+07	2.628286E+07	2.257771E+08	2.964691E+07
1979	1.429723E+07	2.556648E+07	2.234092E+08	3.006136E+07
1980	1.400597E+07	2.490830E+07	2.203072E+08	3.038758E+07

	QD	ED	WP	PG
1971	2.286837E+07	730912.	29.4413	19.2641
1972	2.440051E+07	4.960592E+06	30.5507	20.3911
1973	2.595869E+07	1.920816E+06	34.7376	25.4039
1974	2.783971E+07	2.089152E+06	37.0025	27.6255
1975	2.992152E+07	2.688624E+06	39.0247	29.4764
1976	3.204269E+07	3.723104E+06	40.7977	31.0033
1977	3.421773E+07	5.127056E+06	42.4051	32.3199
1978	3.648106E+07	6.834144E+06	43.9014	33.5054
1979	3.886203E+07	8.800176E+06	45.3195	34.6069
1980	4.138728E+07	1.099970E+07	46.681	35.6537

TABLE 3b: FORECAST WITH ERICKSON-SPANN EQUATIONS 'STATUS-QUO' REGULATION

	ND	DR	R	QS
1971	4.488216E+06	9.128078E+06	2.365706E+08	2.213746E+07
1972	6.057225E+06	1.014869E+07	2.232570E+08	1.943992E+07
1973	1.211802E+07	1.885488E+07	2.241633E+08	2.403787E+07
1974	1.726978E+07	2.708805E+07	2.262342E+08	2.623699E+07
1975	2.024493E+07	3.326627E+07	2.323595E+08	2.850366E+07
1976	2.123979E+07	3.628386E+07	2.396301E+08	3.053814E+07
1977	2.286834E+07	3.851870E+07	2.474838E+08	3.237163E+07
1978	2.439288E+07	4.058739E+07	2.559147E+08	3.406507E+07
1979	2.580491E+07	4.252078E+07	2.649117E+08	3.565854E+07
1980	2.709850E+07	4.430917E+07	2.744289E+08	3.717752E+07

	OD	ED	WP	PG
1971	2.287107E+07	733616.	29.4217	19.2641
1972	2.440819E+07	4.968272E+06	30.523	20.3911
1973	2.597309E+07	1.935216E+06	34.7115	25.4039
1974	2.780651E+07	1.569520E+06	37.467	28.2693
1975	2.975219E+07	1.248528E+06	40.2632	31.1191
1976	3.163144E+07	1.093296E+06	42.9826	33.831
1977	3.344909E+07	1.077456E+06	45.6698	36.465
1978	3.523405E+07	1.168976E+06	48.3555	39.0719
1979	3.701331E+07	1.354768E+06	51.0529	41.6772
1980	3.881328E+07	1.635760E+06	53.7669	44.2936

TABLE 3C: FORECAST WITH ERICKSON-SPANN EQUATIONS "DEREGULATION" POLICY

	ND	DR	P	QS
1971	4.488216E+06	9.128078E+06	2.365796E+08	2.213746E+07
1972	6.957225E+06	1.014869E+07	2.282570E+08	1.943992E+07
1973	1.211802E+07	1.885488E+07	2.241638E+08	2.403787E+07
1974	3.400229E+07	4.382056E+07	2.393009E+08	2.990616E+07
1975	3.738898E+07	5.889662E+07	2.651106E+08	3.445568E+07
1976	3.970394E+07	6.530074E+07	2.935793E+08	3.835563E+07
1977	4.293018E+07	6.971283E+07	3.232036E+08	4.179189E+07
1978	4.576720E+07	7.365274E+07	3.538465E+08	4.491539E+07
1979	4.843958E+07	7.728998E+07	3.854477E+08	4.781789E+07
1980	5.088653E+07	8.063710E+07	4.179095E+08	5.055586E+07

	QD	ED	WP	FG
1971	2.287558E+07	738128.	29.3814	19.2641
1972	2.442154E+07	4.981616E+06	30.4461	20.3911
1973	2.599947E+07	1.961600E+06	34.6009	25.4039
1974	2.739530E+07	-2.510864E+06	41.2789	33.6045
1975	2.864208E+07	-5.813600E+06	46.2169	39.1969
1976	2.965528E+07	-8.700352E+06	50.5423	43.8168
1977	3.049614E+07	-1.129574E+07	54.5723	47.9422
1978	3.122646E+07	-1.368893E+07	58.4552	51.8117
1979	3.189435E+07	-1.592354E+07	62.2621	55.5454
1980	3.254064E+07	-1.801522E+07	66.0285	59.2072

TABLE 4A: FORECAST WITH MACAVOY-PINDYCK EQUATIONS "COST OF SERVICE" REGULATION

	ND	DR	P	QS
1971	4.488207E+06	9.128069E+06	2.365796E+08	2.213746E+07
1972	4.253788E+06	8.345258E+06	2.265556E+08	1.933866E+07
1973	6.307435E+06	1.202976E+07	2.166469E+08	2.302832E+07
1974	8.535175E+06	1.475468E+07	2.033676E+08	2.375515E+07
1975	1.102974E+07	1.850922E+07	2.040371E+08	2.470130E+07
1976	1.283586E+07	2.189066E+07	2.016223E+08	2.582840E+07
1977	1.389240E+07	2.413533E+07	2.004632E+08	2.699986E+07
1978	1.515307E+07	2.599685E+07	2.001672E+08	2.820294E+07
1979	1.662017E+07	2.799003E+07	2.008183E+08	2.947814E+07
1980	1.829707E+07	3.027213E+07	2.025957E+08	3.087246E+07

	OD	ED	WP	PG
1971	2.286837E+07	730912.	29.4413	19.2641
1972	2.440174E+07	5.063088E+06	30.5391	20.3757
1973	2.599843E+07	2.970112E+06	34.4305	24.8997
1974	2.794315E+07	4.188000E+06	36.5002	26.57
1975	3.008530E+07	5.384000E+06	38.531	28.5752
1976	3.224350E+07	6.415104E+06	40.4532	30.3238
1977	3.442693E+07	7.427072E+06	42.2494	31.9483
1978	3.667042E+07	8.467472E+06	43.941	33.466
1979	3.900496E+07	9.526816E+06	45.5551	34.9094
1980	4.145877E+07	1.058630E+07	47.1139	36.307

TABLE 4B: FORECAST WITH MACAVOY-PINDYCK EQUATIONS "STATUS-QUO" REGULATION

	ND	DR	R	OS
1971	4.488207E+06	9.128069E+06	2.365796E+08	2.213746E+07
1972	4.253788E+06	8.345258E+06	2.265556E+08	1.933866E+07
1973	6.307435E+06	1.202976E+07	2.166469E+08	2.302832E+07
1974	8.535175E+06	1.475468E+07	2.086394E+08	2.397998E+07
1975	1.119758E+07	1.859826E+07	2.033773E+08	2.522939E+07
1976	1.336201E+07	2.229262E+07	2.005171E+08	2.667690E+07
1977	1.496317E+07	2.512824E+07	1.991807E+08	2.816627E+07
1978	1.680611E+07	2.774139E+07	1.991388E+08	2.968643E+07
1979	1.889909E+07	3.059134E+07	2.005758E+08	3.128430E+07
1980	2.125266E+07	3.382166E+07	2.037698E+08	3.3012[illegible]E+07

	OD	ED	WP	PG
1971	2.287107E+07	733616.	29.2672	19.2641
1972	2.440944E+07	5.070784E+06	30.5113	20.3757
1973	2.601285E+07	2.984528E+06	34.4039	24.8997
1974	2.792301E+07	3.943024E+06	36.8586	27.2293
1975	2.995710E+07	4.727712E+06	39.5437	29.8448
1976	3.191163E+07	5.234736E+06	42.3263	32.6296
1977	3.378294E+07	5.616672E+06	45.1335	35.4537
1978	3.559786E+07	5.911424E+06	47.9602	38.3016
1979	3.738211E+07	6.097808E+06	50.3184	41.1911
1980	3.916074E+07	6.148736E+06	53.7153	44.135[illegible]

TABLE 4C: FORECAST WITH MACAVOY-PINDYCK EQUATIONS "DEREGULATION" POLICY

	ND	DR	R	OS
1971	4.488207E+06	9.128069E+06	2.365796E+08	2.213746E+07
1972	4.253788E+06	8.345258E+06	2.265556E+08	1.933866E+07
1973	6.307435E+06	1.202976E+07	2.166469E+08	2.302832E+07
1974	8.535175E+06	1.475468E+07	2.069231E+08	2.570091E+07
1975	1.222402E+07	1.903214E+07	2.000967E+08	2.722198E+07
1976	1.554927E+07	2.409290E+07	1.969169E+08	2.880539E+07
1977	1.842626E+07	2.879432E+07	1.969871E+08	3.042963E+07
1978	2.066306E+07	3.257422E+07	1.993797E+08	3.208533E+07
1979	2.318312E+07	3.626139E+07	2.039483E+08	3.382296E+07
1980	2.600168E+07	4.025725E+07	2.108852E+08	3.570362E+07

	OD	ED	WP	PG
1971	2.287558E+07	738128.	29.3814	19.2641
1972	2.442278E+07	5.084128E+06	30.4343	20.3757
1973	2.603922E+07	3.010899E+06	34.2932	24.8997
1974	2.763365E+07	1.932736E+06	39.6863	30.9719
1975	2.915642E+07	1.234432E+06	44.0148	35.511
1976	3.044870E+07	1.643312E+06	48.2355	39.945
1977	3.153723E+07	1.107600E+06	52.377	44.2772
1978	3.247090E+07	385568.	56.4561	48.5199
1979	3.329237E+07	-530592.	60.5079	52.7225
1980	3.403954E+07	-1.664080E+06	64.5583	56.9257

5. Conclusion

Clearly then, policy proposals for dealing with the natural gas shortage are very sensitive to the particular model that is used for exploration and discovery. The three alternative formulations for exploration and discovery that we have examined in this paper suggest very different price policies for dealing with the shortage. Our own priors would favor the 15¢ price increase as being the most reasonable, but it is at least clear that the whole question of the dynamics of exploration and discovery is crucial to the design of regulatory policy.

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